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Invited Paper

Microwave Photonic Applications of MEMS Technology

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Abstract

We describe RF MEMs switches and their applications to tunable filters and switchable antenna elements. We describe different scenarios where RF Photonic systems can benefit from RF MEMs device development.

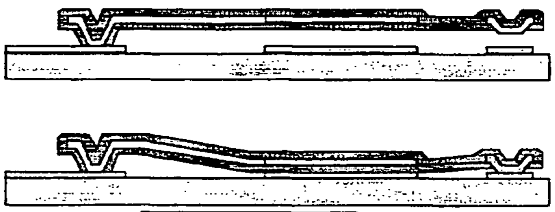
This paper will discuss the potential impact of RF MEMs technology on photonic systems. We first review recent advances in the field of microfabricated electromechanical systems (MEMS) that have demonstrated microwave switches with measured insertion loss below 0.2 dB over broad band ranges up to 45 GHz. We describe the application of these switches to tunable filters and switchable antenna elements. Specifically, we describe the demonstration of a tunable stub circuit with integrated RF MEMs and a switchable frequency antenna where the RF MEMs devices control the frequency of operation of a dipole element. In closing we describe different scenarios where RF Photonic systems can benefit from RF MEMs device development.

A surface-micromachined, electrostatically-actuated, ohmic-contact MEMS switch has been developed for microwave applications. The switch has an actuation voltage of 30 V, a response time of 20 µs, and mechanical robustness to withstand 10^9 actuations. RF performance of greater than 50 dB of isolation below 2 GHz and less than 0.2 dB of insertion loss from DC through 40 GHz has been measured.

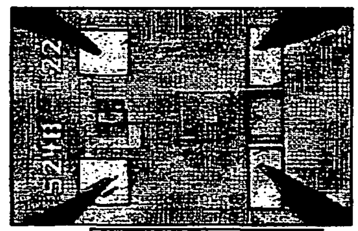
The design is based on a suspended cantilever structure typical of many MEMS switch efforts (1-5), with side-view schematic illustrations of both open and closed configurations shown in Fig. 1. The switch design relies on a key feature that separates the electrode pattern for electrostatic interaction from the RF portion of the switch. In order to maximize RF performance, a metallization layer with very high conductivity was desired. The RF MEMS switches have been demonstrated on GaAs substrates, although the process is compatible with other substrate materials such as InP or high resistivity silicon. A microphotograph of a completed RF MEMS switch is shown in Fig. 2.The insertion loss of one switch with an actuation voltage of 20 V is shown in Figure 3. The insertion loss is less than 0.2 dB from DC through 40 GHz when the switch is closed. The DC resistance across a bonded switch in its closed position is 1.6 Ω. It is interesting that the insertion loss for a 1.6 Ω resistance is calculated to be 0.14 dB, almost exactly measured insertion loss of the switch. The switch isolation when open is >50 dB at low frequencies, and it decreases slowly to 27 dB at 40 GHz. The resonance at 8 GHz is caused by a capacitive coupling to the electrostatic electrodes. The switching speed for this is better than 50 µs, with an actuation voltage of 25 V. Furthermore the RF power handling of this switch has been measured to be better than 1 W at 2.2 GHz.

We fabricated a new reconfigurable notch filter utilizing microelectromechanical (MEM) switches that operates at discrete frequencies whose accuracy only depends on microstrip fabrication and temperature variations. As shown in Figure 4, a microstrip line is loaded with open stubs that provide a frequency dependent impedance in parallel with

the distributed impedance of the microstrip line. By using the RF MEM switches to alternately connect and disconnect stubs or extensions to stubs, the frequency response of the structure will be affected. The RF MEM switches mechanically open and close using an electrostatic force to physically connect and disconnect sections of the microstrip stubs. This experiment points out on of the potential applications of RF MEMs to photonic systems, namely tunable filters and tunable impedance matching. By placing RF MEMs based filters in the front end we can design tunable front end for optimum matching.



a) Side view



b) Top view photo

Figure 1a. Side-view schematic illustrations of MEMS switch in open and closed positions. 1b). The RF path is in the vertical with the electrodes making a hammer-head like connection to the RFF microstrip line. The total die size is 500 μm by 700 μm.

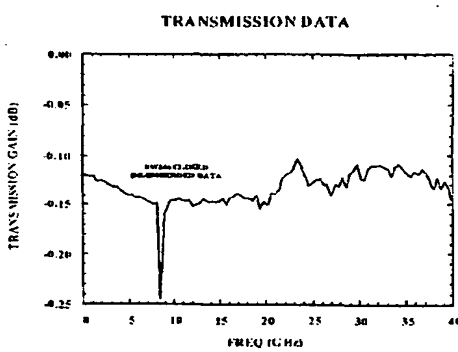


Figure 2. RF Insertion loss of a closed MEMS switch.

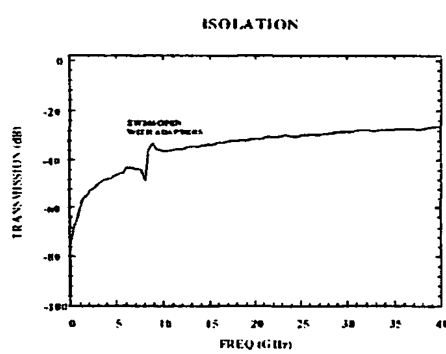


Figure 3. Isolation characteristic of an open MEMS switch.

The low insertion loss and high isolation of RF MEM switches facilitate this approach, which is not as practical using lower performing semiconductor switches. The microstrip filters were fabricated separately on a Duroid substrate. The frequency response of one of the filter is shown in Fig. 5.

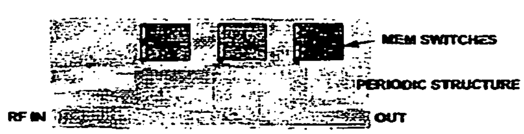


Figure 4. Illustration of frequency-agile filter with RF MEM switches

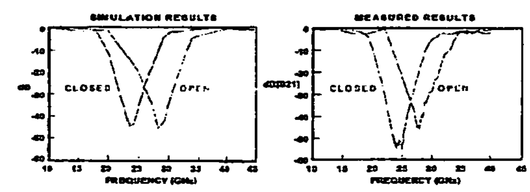


Figure 5: Data for the reconfigurable filter with MEM switches open and closed.

We demonstrated a dual band switchable antenna that utilizes the RF MEMs switches. Fig. 6 shows a diagram of a dual frequency aperture-coupled dipole antenna. The MEM switch is utilized in the construction of a dual frequency antenna that not only allows the transmission and reception at two widely spaced frequencies, but also provides isolation between the selected and unselected bands. To select a frequency band, both switches are either turned "on" (conducting, for the lower frequency band) or turned "off" (non-conducting, for the upper band).

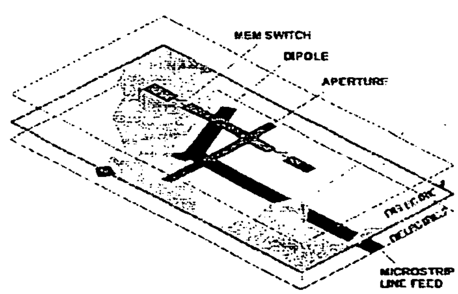


Figure 6. Diagram of a dual frequency aperture-coupled dipole antenna

Applications to RF Photonics of RF MEMs technology are already being pursued. Perhaps it is best to list the potential areas where new RF MEMs circuits will have an impact on RF Photonic systems. As mentioned previously tunable filter circuits can lead to tunable impedance matching of the RF Photonic front ends. As demonstrated in this paper, RF MEMs can change the frequency or radiation pattern of an antenna. The development of Reconfigurable Apertures using RF MEMs is fast becoming a very important thrust in antenna research. The low loss of the RF MEMS switch will be exploited for RF Phase Shifter development, where the insertion loss will be extremely low (a few dB) at high frequencies. This should cause most photonic beam steering developers to rethink their present architecture designs, since many have been based on eliminating these lossy elements with photonic substitutes – TTD or phase steered arrays.

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New MEMs Circuit	Application to RF Photonics	R&D Status
RF MEMs Switched Filters	Agile Front End Match for Band Switching	Several RF Filter Programs Underway
Reconfigurable Antennas	Band Switching Antenna Elements	Several Research Groups in Pursuit
RF MEMs Phase Shifters (4-6 bit)	Extremely Low Loss Switched Delay Lines	Raytheon and HRL Programs

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